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D. W. MAY, SPECIAL AGENT IN CHARGE.

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SOME PRINCIPLES IN MANURING WITH LIME AND MAGNESIA

BY

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SOME PRINCIPLES IN MANURING WITH LIME AND MAGNESIA.

It is very advantageous for plants if the mineral nutrients are not only supplied in a suitable condition but also in the same ratio to each other in which the plants need them for their best development. The ratio of lime to magnesia, however, deserves special care, and in regard to this ratio the following conclusions have been arrived at which are based on theory as well as on numerous experiments.(1)

1. It is always an unfavorable condition when the magnesia content of a soil is essentially higher than the lime content. For many plants it is also unfavorable when the lime content is more than three times as high as the magnesia content.

2. Since by the application of barnyard manure sufficient lime and magnesia are supplied in easily available form, the original lime-magnesia ratio in the soil, which we designate for brevity's sake as "limefactor", does not play such a significant part as in the case of mineral manuring, where potassa, phosphates and nitrogen are added. Sometimes lime is added also, but this does not take into consideration the need of magnesia nor the ratio of lime to magnesia in the soil.

Magnesia is just as important as potassa, being present in every living cell, a constituent of chlorophyll green, and it is especially concerned in germination. In leaves lime preponderates over magnesia, but the reverse is true in the seeds.

3. Most kinds of cereals develop best when the lime content is equal to the magnesia content or does not exceed this proportion. Oats yield an essential decrease in harvest when the lime-magnesia ratio exceeds 2:1, maize develops better at 2:1 than at 1:1. Flax behaves similarly to rice, barley and wheat.

4. Leguminous plants and buckwheat, and probably many other plants require relatively more lime than do cereals; the limefactor 3:1 being here more favorable.(2)

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(1) The following literature on this subject may be mentioned: O. Loew, On the functions of lime and magnesia, Flora 1892, pp. 286; The Physiological Role of Mineral Nutrients, Bul. No. 18 and No. 45, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C., 1899 and 1903; O. Loew and D. W. May, The Relation of Lime and Magnesia to Plant-growth, Bul. No. 1 Bureau of Plant Industry, Washington, D. C. 1901; cf., also the communications of Aso, Daikuhara, Furuta, Katayama, and others in the Bulletins of the College of Agriculture, Tokyo University, vol. IV., pp. 362—389; vol. V., pp. 495—501; vol. VI., pp. 97—103 and pp. 345—347; vol. VII., pp. 58—65 and 579—615; and Bulletin of the Agricultural Experiment Station, Tokyo, vol. I. Further, O. Loew, Landwirtschaftliche Jahrbücher, 1892 pp. 561; 1895 pp. 131 and 1896 pp. 587. Zeitschrift für das Landw. Versuchswesen in Oesterreich 1905, pp. 583; Fühling's Landw. Zeitung 1909 pp. 355. Bernardini e Corso; Intorno al l'influenza di vari rapporti fra calce e magnesia sullo soiluppo delle piante, Portici 1907. Bernardini e Siniscalchi, Ibid. 1908. Hansteen: Nyt Magazin fur Naturvidansk, vol. 47, (Christiania 1909). A. Voelcker, Report on Field and Pot culture experiments 1907, pp. 26. L. Portheim u. Semec, Flora 1898 pp. 263.

(2) The ratio 3:1 would correspond to a mixture of twice as many molecules CaO as MgO. The ratio 1,4:1 would correspond to a mixture of an equal number of molecules.

5. Plants, like tobacco and grape, which can exclude an excess of absorbed lime from further physiological influence by precipitation as calcium oxalate in the cells of leaves and stem, can also show a very favorable development in such cases where the lime content of the soil exceeds the magnesia content by more than threefold. However, there is a limit in this respect, since the regulative powers of the plants are imperfect.

6. Frequently the limefactor in soils is found between 1:1 and 3:1, but very unfavorable limefactors are by no means of rare occurrence. There exist e. g. soil formations in which the lime content exceeds the magnesia content twentyfold and over, and others again, in which the magnesia content is 10 to 20 times that of the lime content. Since, however, an augmentation of any constituent, say lime by 0,1% of a soil of a volume weight of 1250 would already require as much as 2500 kilos of lime per hectare to a depth of 20 cm., it becomes clear, that the regulation of the limefactor in soils can only be economically carried out with soils containing less than 1-2% of lime or magnesia. Sandy soils frequently contain less than 1% of each and still may show unfavorable limefactors, e. g. 0,8% CaO and 0,04% MgO or the reverse. In poor sandy soils where both the bases are present in about equal amounts ground magnesian (1) limestone should be used to increase the percentage of both. If there exists an excess of magnesia, pure limestone, free of magnesia should be applied; if, however, the magnesia content is far below the lime content, magnesite meal (2) or annually small doses of magnesium sulphate should be added. An application of pure limestone on poor sandy soils has often caused a decreased harvest to the surprise of the owner. It may be safely assumed that in such cases the magnesia content of the soil was far below the lime content and that an increase of lime rendered therefore the limefactor still more unfavorable than it was.

7. From a practical point of view the ratio of 2 parts of lime to 1 part magnesia in the soil would be the most desirable, since this ratio approaches on the one side the best limefactor for cereals, and on the other the best for the leguminous plants.

8. The lime magnesia ratios mentioned thus far hold good for the condition where both bases are present in the same state of availability, as e. g. when they exist in the soil as humates, carbonates or hydrous silicates (as dolomitic or as zeolithic particles). If, however, the one should be present in a water soluble form, the other in a form not soluble in water, then the ratio entering the root would of course differ from the ratio present in the soil, the former being capable of rapid absorption by the plant, the other not. (3) This point is especially important when manuring is considered.

9. In cases where the regulation of the limefactor in a soil

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(1) Magnesian limestone (dolomite) may contain as much as 20% MgO and over.

(2) Magnesite meal, containing only 1,88% CaO is put on the market by Merck's Guano Works in Harburg a. E., Germany, at a cost of about 3 Marks per 100 kilos.

(3) Experiments have shown that magnesium sulphate is about ten times as effective as the natural magnesium carbonate. Burnt magnesia and the artificial (basic) carbonate may in effectiveness even exceed an equal amount of the sulphate.

would be excluded for economical reasons, the proportion of lime to magnesia should be improved as far as economy would permit. Sulphate of lime (gypsum) and sulphate of magnesia (1) may be applied in this case, being more effective than the carbonates. But sulphates should be applied only when there is some carbonate of lime in the soil, since continued use of sulphates on the same soil is apt to produce gradually an acid reaction. The application of gypsum in such cases should be made in conjunction with ground limestone, if carbonate of lime is absent in the soil.

10. Some care has to be exercised in manuring with magnesium sulphate. Clayey and loamy soils can be treated at first with 200 to 500 kilos per hectar, eventually with more, but on sandy soils such large doses would not be advisable, partly because the sulphate may be lost again by leeching. Smaller doses, applied annually, are preferable. The most effective form of application is a top dressing with dilute solutions.

11. In cases of an excess of magnesia over lime in a soil it will be of great advantage to apply the nitrogen in the form of calcium nitrate or as the so called lime nitrogen (calcium cyanamid), since in this way a special manuring with lime may be avoided. When calcium nitrate or lime nitrogen is applied on soils too rich in lime, then magnesium sulphate should be applied in conjunction with it.

12. When heavy clay or loam soils have to be loosened by liming, the limefactor in the soil should be considered. Accordingly pure limestone should be applied, when the magnesia content in the soil is higher than the lime, while magnesium limestone should be used if the reverse is the case. Thus at the same time the soil is loosened and the limefactor improved.

13. It is also necessary to consider the limefactor when correcting the acid or alkaline reaction. Soils of alkaline reaction should receive gypsum for neutralization if the magnesia content is higher than the lime and magnesium sulphate when the magnesia content is too far below the lime.

14. It may happen that loosening a heavy clay soil or neutralizing the acidity of a soil will have a much more powerful influence on the productivness than the correction of the limefactor but this is no reason why an additional advantage should not be secured when those evils are remedied.

Acid compounds, as superphosphates or acidity producing compounds, as sulphates, should be avoided on acid soils while alkalinity producing compounds, as nitrates, should not be used on alkaline soils (2)

The following pages will serve to illustrate the principles mentioned.

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(1) Magnesium sulphate is obtained as a by-product in the production of potassium chlorid and is sold under the name of Kieserit (with 70 per cent $MgSO_4$) at 1.3 Marks per 100 kilos at Stassfurt, Germany.

(2) Some attention ought to be paid in this direction also to the frequent spraying with ferro sulphate against weeds. Since that compound is generally applied in a concentration of 20 per cent. and at the rate of 52 gals. to the acre, an acid reaction might thereby gradually develop in soils that are free of carbonate of lime. A moderate liming will be the remedy.

II

THEORY OF THE FUNCTIONS OF LIME AND MAGNESIA.

The function of lime in plant cells can be inferred from the study of the action of neutral potassium oxalate and sodium fluoride on the nuclein and chlorophyll bodies. These two salts have the property of withdrawing lime from other compounds and since we can observe a powerful poisonous action of these salts on the nuclei and chlorophyll bodies (1) it can be inferred that this is due to this most characteristic property of these two salts. Hence, it seems most natural to assume that these organoids contain important lime compounds of proteids as a part of their organization.

One of the most characteristic properties of magnesium salts is the ready dissociation to acid and base. Since for the formation of organic compounds of phosphoric acid in the cells, it is necessary that this acid first be separated from the base with which it is combined. it is certainly most natural to assume that this process is most easily accomplished with magnesium phosphate. Thus the function of magnesia would be easily explained. This base becomes therefore very important in the production of lecithin and nucleoproteids. The latter are concerned in building up the nucleus and therefore also in the process of cell division and multiplication, that is, plant growth. While calcium is fixed in the organized structure, magnesium is movable, serving mainly in the form of secondary phosphate as carrier of assimilable phosphoric acid, which role can be repeated as often as the magnesia is again transformed into phosphate by double decomposition.

It follows from this theory that, in case an excess of lime is taken up, the assimilation of phosphoric acid will be rendered more difficult, since this acid will chiefly combine with the lime and thus the chance for the formation of magnesium phosphate will be diminished. The effect will be the same as if the amount of available phosphoric acid in the soil were lessened—that is, the growth of the plant will be retarded and even starvation phenomena may set in. Many plants avoid this evil effect of an excess of lime in the juices by the precipitation of a part of the lime as oxalate, while others secrete an excess of lime as carbonate.

If, on the other hand, magnesia is taken up in considerable excess over lime a still more injurious action is observed. Plants succumb soon when placed in a dilute solution of magnesium salts. None but calcium salts, can prevent this effect. In fact, magnesium salts can exercise their nutritive functions only in the presence of a sufficient amount of calcium salts. The plants can not, as with lime, turn an excess of magnesia into an insoluble form and thus

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(1). This effect can best be studied with Spirogyra, a higher alga, having a large screw-like chlorophyll body and a spindle form nucleus. A few minutes action of a 1-2 per cent. solution of potassium oxalate suffices to show the highly peculiar contraction of the nucleus to a mere thread and the incipient vacuolization of the chloroplast. Spirogyra setiformis (or crassa) has the largest cells and hence is the most convenient species for study,

render it innocuous. The formation of globoids or of insoluble magnesium protein compounds may come into consideration only in certain cases.

The injurious action of magnesium salts has been previously explained by the writer, as follows: The calcium nucleo-proteids of the organized structures are transformed into magnesium compounds by the action of soluble magnesium salts, the calcium of the former entering into combination with the acid of the magnesium salt. By the transformation of the organized calcium nucleo-proteids into magnesium nucleo proteids the capacity for imbibition will change, which must lead to a disturbance in the structure that will prove fatal. Only the simultaneous presence of dissolved lime salts can prevent this effect, according to the law of mass. The writer noted, among other observations, that certain algae, such as Spirogyra, died in five days in a magnesium nitrate solution of 1 part to 1,000, while they remained alive for a number of weeks in this solution when 0.3 parts calcium nitrate was present. Of course, magnesium in the form of water-insoluble compounds in the soil would act injuriously to a much less degree than soluble magnesium nitrate or sulphate; but nevertheless injury will result in time if the amount of lime is too small.

On the basis of this theory the inference was logically drawn by the writer in 1892, that the apparent physiological antagonism (1) of lime to magnesia requires a balancing of the quantities of both bases for the best development and highest yield of crops. In other words, the highest yield, will under otherwise favorable conditions, be realized only when lime and magnesia can enter the roots in a given ratio.

It is a further interesting fact that the lowest forms of algae and fungi do not require lime, which may be explained by the low and simple organization of their nuclei. In accordance with this fact the logical conclusion (2) is reached that neither magnesium sulphate nor potassium oxalate can exert any poisonous action on these low organisms; this has been verified by the writer.

On further details and inferences of this theory see Bulletin No. 45 of the Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. 1903.

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(1). This physiological antagonism was recently observed also for the animal body by Meltzer and Auer in the Rockefeller Institute for Medical Research. (Am. Jour. of Physiol. 1908.)

(2). Sodium fluoride is much less poisonous for lower forms of algae and fungi than for higher algae and the phenogams. This compound exerts a secondary action on the living protoplasm, cf. O. Loew, Flora 1905, pp. 333.

III

CULTURE EXPERIMENTS.

Numerous culture experiments with various plants, in water, sand, and soil, were carried out during the last ten years, applying both lime and magnesia in various ratios; in some cases as nitrates, in others in the form of natural carbonates.

In order not to interfere with the absorption of phosphoric acid by increasing the amount of carbonate of lime in the soil, the use of bone phosphate and tri-calcium phosphate as phosphatic manure was avoided, the secondary calcium phosphate was only exceptionally used, the primary or acid phosphate of calcium or potassium was usually applied, and sometimes also the secondary sodium phosphate. Moreover, in all our experiments the soil was richly manured in order to meet the objection that favorable effects in certain pots might have been due merely to potassa, set free from the soil by carbonate or sulphate of lime.

Indeed all these experiments have demonstrated that the best development under given conditions depends upon a certain ratio of lime to magnesia.

As to unfavorable ratios of lime to magnesia found in soils it may be pointed out that a considerable excess of magnesia over lime is, as far as the limited number of analyses show, a condition especially frequent in soils of tropical countries, as those of Porto Rico, (1) Samoa, Madras province of India, Cameroon, the Congoland, also in some of the southern States of the Union, Louisiana and Alabama. In certain parts of Germany and Austria, especially in the province of Kærnten, the content of magnesia in the soils often exceeds considerably that of lime.

The reverse condition, an undue preponderance of lime over magnesia, is also of frequent occurrence. There exist soil formations containing only traces of magnesia but with a lime content of 1 to 20 per cent, as is the case in the Palatinate province of Germany.(2)

The analyses of soils and of river deposits which are especially noted for fertility, never show an excess of magnesia over lime, but always a moderate excess of lime over magnesia. Generally this latter condition is more favorable than the former.

Some authors have objected stating that the essential factor in these experiments might have been due to the absolute amount of lime or magnesia in the soil and not to the ratio of lime to magnesia. This opinion, however, is entirely unfounded. Thus our first water and sand cultures have already shown that the ratio alone is responsible for the yield. These tests were carried out keeping the sum of both bases constant, merely changing the ratio of one base to

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(1) Cf. the analyses of P. L. Gile in the reports of the Agr. Exp. Station, at Mayaguez, P. R. It is to be regretted that no country possesses thus far a systematic chemical soil survey showing the stores of mineral nutrients available immediately and later on. Only Japan has carried on a chemical survey in connection with the Geological Survey.

(2) Cf. O. Loew, Chemiker Zeitung, 1909 No. 14.

the other, hence, there was only a relative but never an absolute excess that could act injuriously. In other experiments the effect of raising both bases at the same time was compared with the effect of one base only, the results of these experiments showing also the fallacy of the objection. Special trials have shown that a soil after overliming can be restored to its original state by adding magnesia.(1) It may be mentioned that there exist soils with 30 per cent lime in the form of carbonate which amount might at first thought easily be declared injurious, but since such a soil showed great productiveness when superphosphate was applied the writer subjected it to an analysis that revealed a magnesia content of fully 11 per cent which, in itself would also seem injuriously high. But since the ratio of lime to magnesia was here favorable, namely, 3:1, the fertility of the soil was easily explained in spite of the apparently injurious amount of lime on the one side and of magnesia on the other.

A short account of some of the experiments may be given here to illustrate the principles enounced. May(2) carried on experiments with oats, wheat, beans and tobacco, from which we mention the following trial:

To 30 kilograms of pure white sterilized sand the following nutrients were added :

	Per cent.
K_2HPO_4	0.1
KH_2PO_4	0.1
KNO_3	0.2
$(NH_4)_2SO_4$	0.1
$Fe\ SO_4$	Trace.

These salts were finely powdered, mixed first with a small quantity of sand, and then with the whole. The sand was put into sixteen pots, in two series of eight each, calcium and magnesium nitrates being added in solution in such proportions as to correspond to the following ratios:

Mg0	0.8	per cent	Ca0,	0.1	per cent.
Mg0	0.7	"	Ca0,	0.2	"
Mg0	0.6	"	Ca0,	0.3	"
Mg0	0.5	"	Ca0,	0.4	"
Mg0	0.4	"	Ca0,	0.5	"
Mg0	0.3	"	Ca0,	0.6	"
Mg0	0.2	"	Ca0,	0.7	"
Mg0	0.1	"	Ca0,	0.8	"

(1) Cf. Maki and Tanaka, Bul. College Agric. Tokyo. Vol. VI, and Landw. Jarhrb., 1906, pp. 533.

(2) Bul. No. 1 Bureau of Plant Industry, Washington, D. C. 1900.

On July 11 the pots were planted to wheat. On July 18 the wheat plants had made growths as follows:

MgO	CaO	Growth
Per cent	Per cent	Centimeters
0.1	0.8	2.5
0.2	0.7	2.5
0.3	0.6	12
0.4	0.5	18
0.5	0.4	15
0.6	0.3	5
0.7	0.2	5
0.8	0.1	2.5

On July 23 the growth had progressed in the same relative proportion.

On August 6 the plants in one series of pots were taken up and the root systems examined, with the following results:

MgO	CaO	Growth	Condition
Per cent	Per cent	Centimeters	
0.1	0.8	6	Bushy, poorly developed.
0.2	0.7	6	Bushy, poorly developed.
0.3	0.6	16	Bushy, well developed.
0.4	0.5	16	" developed.
0.5	0.4	7	No root hairs.
0.6	0.3	3	No root hairs.
0.7	0.2	3	No root hairs.
0.8	0.1	4	No root hairs.

The root systems as well as the growth above ground, showed the most favorable conditions to be present where the amount of soluble CaO was slightly in excess of the soluble MgO. Where the CaO was was greatly in excess the root system was apparently healthy, but poorly developed. Where the MgO was in great excess the root system showed an unhealthy condition, an absence of root hairs, and later a shrinkage and discoloration of the larger portion of the root.

On August 20, forty days from the time of planting, the wheat in the remaining series of eight pots, with the exception of the extremes, had become more nearly equal in height. The general thriftiness of the plants, however, appeared to range as before reported, the pots with lime moderately in excess of magnesia making the best growth, the plants in the pot with MgO 0.4 per cent and CaO 0.5 per cent being larger and stronger, and the thriftiness ranging from this ratio down to MgO 0.2 and CaO 0.7, and MgO 0.7 and CaO 0.2 per cent. In the two extreme pots the plants were dead."

It is, of course, the root which will first be influenced by the ratios of lime to magnesia. Not only is the growth retarded by an unfavorable ratio and the weight of the root very much diminished, but the production of root hairs also depends much upon the proper ratio. Lime in moderate excess favors the formation of root hairs much more than does magnesia, as the writer had already observed in 1890. This was confirmed recently by Voelcker in England (l. c.) Hansteen in Norway (l. c.,) and Portheim in Vienna (l. c.) As to the weight of the root, Takeuchi (1) observed a decrease in oat roots from 13, 5 g. to 4,4 g. when in a soil the lime-magnesia ratio of 1.2:1 was changed to 10:1, by adding limestone meal.

Hartwell and Pember (R. I. Experiment Station Twenty-fifth Annual Report, pp. 274) mention the following: "In those series containing a large excess of magnesia the main roots were shorter and the number and extent of the lateral branches were very much reduced as compared with the series where there was a larger proportion of calcium." When the excess of magnesia is relatively small, the growth of the root may even be stimulated, (1) but in such cases the writer has repeatedly observed a diminished development of root hairs, which are such important organs for the absorption of the mineral nutrients from the soil.

To a loose loamy soil, showing the limefactor CaO: MgO=1:1. Furuta added quick lime in such amounts that the ratios 2:1 and 3:1 were produced. The total yields of buckwheat (8 plants in pots with 8 kilos of soil), cabbage (7 plants) and oats (11 plants) were as follows:

Limefactor	Buckwheat	Cabbage.	Oats.
	grams.	grams.	grams.
1:1	190	390	297
2:1	220	475	280
3:1	382	375	260

Hence, the most favorable ratio for buckwheat is 3:1, for cabbage 2:1 and for oats 1:1.

In the experiments of Bernardini and Corso at Portici the best ratio for oats (in water cultures) was found to be 1:1. Further experiments showed, however, that in soil culture under certain conditions the ratio 2:1 can also produce about equally good results with oats, a notable decrease setting in at 3:1. The yield decreases with the further widening of the ratio, thus Takeuchi (l. c.) observed a decrease of two-thirds with oats when the lime factor of a soil was changed from 1:1 to 10:1. Also for rice, wheat, rye, and barley the best limefactor was found=1.1, as the experiments of Aso. Bernardini and Corso and of Konowalow have shown. In six experiments with onions in which not only sand culture but also sandy loam had been used Katayama found 2:1 as the best limefactor. For the leaf pro-

(1) Bul. College of Agriculture, Tokyo, Vol. VII.

(1) O. Loew, Flora 1892, Exp. with Tradescantia.

duction of the mulberry tree the best ratio was found to be 3:1 by Aso and by Nakamura for flax 1:1. In general it may be said that the more leaf surface produced in a given time by the plant the more lime is needed. Thus, Bernardini and Corso, found the best ratio for maize to be 2:1.

The leaves of the plant are the organs richest in lime, which is in accordance with the inference that lime is a constituent not only of the nuclei but also of the chlorophyll bodies. In the seeds, however, the magnesia predominates over lime, which is a favorable condition for germination. But before the nutrients in the seed are completely exhausted by the young growing plant the relative increase of lime becomes necessary.

A further experiment may be mentioned here which shows the effect of liming when the soil is relatively too rich in magnesia. Daikuhara (1) experimented with a soil from Omagari, Japan, which contained 0.64 per cent lime and 1.91 per cent magnesia. This alluvial humus soil certainly did not suffer from want of lime in itself but only from the unfavorable ratio of lime to magnesia which was 0.3 to 1, a ratio especially unfavorable for beans, buckwheat, tobacco, and also for cereals. It was calculated that for each pot of 10.81 kilos soil 245 grams of calcium carbonate was necessary to make the lime content equal to that of magnesia.

The general manure was:—

	Grams per pot	Ratio per hectar.
Ammonium nitrate	1.71	342 kilo = 112.5 kilo N
Sodium phosphate	1.90	380 " = 75.0 " P_2O_5
Potassium carbonate	0.61	122 " = 75.0 " K_2O

Nine seeds of naked barley were sown November 24, and the young plants when 10 to 12 cm high were reduced in number to 5 of equal size in each pot.

The plants were cut May 31 with the following results:

	Grain	Total plant
	Gms.	Gms.
Original soil	6.24	20.53
Limefactor corrected	14.56	41.41

Hence, the yield was doubled by correcting the unfavorable limefactor in the soil.

An unhealthful excess of magnesia in soils may be counteracted not only by the application of quick lime or limestone meal but also by gypsum, which in certain cases, may even be more efficacious. Generally a mixture of carbonate with some gypsum may be most advantageous. An experiment of Takeuchi (2) may be mentioned

(1) Bull. Exp. Station, Tokyo, Vol. I, No. 1, 1905, pp. 13.

(2) Bul. College of Agr., Tokyo, Vol. VII. No. 5.

which illustrates this. To a soil containing 0.6 per cent lime and 0.5 per cent magnesia soluble in 10 per cent hydrochloric acid was added 0.2 per cent of artificial magnesium carbonate to observe the extent of the depression produced by this addition. Some of the soil thus treated was given gypsum to observe the curative effect. Each eight kilos of the soil was manured with:

5 gms. Potassium sulphate
12 gms. Sodium nitrate
6 gms. Secondary calcium phosphate.

Eight spinach plants were grown per pot. The harvested plants weighed, as follows:

Original soil	177.5 grams.
Magnesium carbonate 0.2 p. ct.	113.3 "
" " plus 0.5 p. ct. gypsum	175.6 "
" " " 0.2 p. ct. "	187.0 "

An experiment on the effect of correcting an unfavorable lime factor in a soil where magnesia was needed was carried out at the suggestion of the writer by T. Nakamura (1) in Tokyo. A soil in Kyushyu principally consisting of hydrous silicates in a very fine pulverulent condition yielded on analysis, among other constituents, 1.76 per cent lime and 0.11 per cent magnesia. (2) Since here the lime content is about seventeen times larger than that of magnesia it was inferred that manuring with magnesia would be very beneficial especially for cereals. In order to observe what amount of magnesium sulphate would be the most favorable, twelve pots, each with nearly ten kilos of air dried soil, were given varying quantities of magnesium sulphate.

No. of Pots	Amount of magnesium sulphate applied per pot.
1 and 7	No magnesium sulphate.
2 " 8	39.36 gms. magnesium sulphate.
3 " 9	78.72 " " "
4 " 10	118.08 " " "
5 " 11	157.44 " " "
6 " 12	196.80 " " "

The experiment was made in duplicate. On November 17, 1903, the magnesium sulphate was well mixed with the pulverized soil. On the succeeding day 0.5 g. P_2O_5 (as disodium phosphate), then 0.25 g. K_2O (as carbonate) and 0.5 g. N (as ammonium chloride) were added per pot. On November 23 barley seeds were sown (9 grains per pot.)

(1) Bul. Exper. Station, Tokyo, Vol. I. No. 1, 1905, pp. 30.
(2) This percentage would certainly have sufficed for full returns, it was alone the ratio to lime which was unfavorable.

The observations made during the experiment and the results obtained are given in the following table:

No. of pots.	1 & 7	2 & 8	3 & 9	4 & 10	5 & 11	6 & 12
$MgSO_4\,7\,H_2O$ applied gms.	0.00	39.36	78.72	118.08	157.44	196.80
Time of germination	Dec. 4	Dec. 5	Dec. 6	Dec. 6	Dec. 11	Dec. 19
" " flowering	May 14	May 4	Apr. 15	May 5	May 18	June 7
" " maturity	Jun 3	May 25	May 25	May 25	Jun. 9	June 9
Number of days from sowing to maturity.	193	184	184	184	199	201
Length of the highest stalk in cm.	105	99	100	98	65	56
Number of stalks with perfect ears.	11	19	22	21	7	1
Number of stalk with imperfect ears.	10	6	3	5	4	1
Number of stalks without ears.	0	0	0	0	1	2
Total number of stalks.	21	25	25	26	12	4
	Grams.	Grams.	Grams.	Grams.	Grams.	Grams.
Straw,	41.63	45.40	50.42	49.52	25.98	10.65
Full seeds,	13.10	16.55	22.10	19.13	4.78	0.58
Empty seeds,	2.05	0.95	0.88	0.85	0.77	0.37
Total,	55.78	63.90	73.40	69.50	31.53	11.60
Proportion of grain, control=100	100	123	169	146	37	4

As seen from the above table the best result was obtained when 78.72 grams of crystalized magnesium sulphate were applied. The plants in this pot flowered 28 days earlier and matured 9 days sooner than those in the control pot, and the plus yield amounted to 69 per cent. However, magnesia applied in excess, exerted a very injurious action on the growth of the plants; while, the application of only a small quantity of magnesium sulphate (0.59 gm. of Mg0 per pot=100 kilog. per hectar) remained, as preliminary experiments had shown, without essential effect.

These results show decidedly that the addition of a certain quantity of magnesia acts very beneficially upon the growth of the plant when the soil contains a large excess of lime over magnesia, and furnish at the same time a further proof of the inference that a maximum yield depends—other things being equal—upon a certain ratio of lime to magnesia entering the plant.

Other cases of favorable action of magnesium sulphate were observed in France and Germany. Larbalétrier and Malpeaux (1)

(1) Ann Agronom. 1896 pp. 20.

report an increase of 23 per cent in sugar beet and of 15 per cent in maize after manuring with magnesium sulphate at the rate of 300 kilos per hectar on an unmanured soil containing 0.2 per cent magnesia and 1.9 per cent lime, (limefactor 9.5:1).

Maercker(1) observed with alfalfa on light soil an increase of 90 per cent after manuring with chlorid of magnesium at the rate of 1000 kilos per hectar. It is to be regretted that he failed to determine the lime and magnesia content of the soil. Very probably the lime was far in excess of the magnesia otherwise this excessive manuring with chlorid of magnesium would certainly have caused a decrease.

Baumann (2) observed with a mucksoil nearly the same decrease in the yield of potatoes when magnesia was omitted in the manure as when phosphoric acid was omitted. With a complete manure co taining also magnesia the total production was 25,100 kilos per hectar; with magnesia omitted the yield was 2,550 kilos less, and with phosphoric acid omitted the yield was lowered by 2,900 kilos. The soil contained only 0.01 per cent magnesia and 0.1 per cent lime, or a limefactor of 10:1.

These examples show the beneficial effect of manuring with magnesia under the conditions mentioned, and demonstrate how unwise it is to neglect the determination of the magnesia content in soils, a neglect practised almost universally at the present day in carrying out soil analyses.

The principles here developed from theory and experiment are of special value for Porto Rico, since soils from various districts contain an excess of magnesia over lime as shown in the analyses made by P. L. Gile. A soil near the experiment station showed 0.60 per cent lime and 3.32 per cent magnesia; hence the amount of magnesia exceeds that of lime 5.5 times. When such a soil happens to be of acid reaction and of very clayey nature, as was here the case, then liming will exert a triple benefit. Indeed, the application of lime at the rate of 3000 pounds per acre on this soil has increased the yield of cane from of 43.96 tons per acre to fully 69.25 tons. It is remarkable that a simultaneous application of rich manure yielded only 61.6 tons per acre.(3)

On the other hand there exist along the northern coast soils with a great excess of lime over magnesia. Thus one sample from a pineapple plantation near San Juan showed 12.24 per cent lime and only.96 per cent magnesia.

Close attention will be paid by the experiment station to the needs of the soils of Porto Rico along this line.

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(1) Mitteilungen der Deutschen Landwirtschafts-Gesellschaft 1895 pp. 185.

(2) Ber. Moorculturanstalt in Bayern 1905, pp. 28.

(3) Cf. Annual Report of the Porto Rico Exp. Station for 1908.